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A Vocational Case-Based Mathematics Learning Model to Improve Metacognitive Abilities and Learning Achievement of Vocational Students

Ni Made Sri Mertasari, I Made Candiasa, Abas Oya

Abstract

Background/purpose. Mathematics has numerous uses for vocational students. Unfortunately, most vocational students are unaware of this, thus neglecting mathematics learning and focusing solely on vocational material. This study attempts to develop a vocational case-based learning model to enhance students' metacognition, enabling them to learn mathematics effectively and efficiently.

Materials/methods. A vocational case-based mathematics learning model was developed using the Borg and Gall framework and validated by experts. Its effectiveness was tested through a quasi-experimental non-equivalent pretest-posttest control group design involving 60 vocational high school students in two classes (an initial trial at SMK Negeri 1 Singaraja and a final trial at SMK Negeri 3 Singaraja). Metacognitive awareness and mathematics achievement were measured using standardized instruments, and data were analyzed with MANOVA.

Results. Expert evaluations confirmed that the model was valid and feasible for classroom use. MANOVA results showed that students in the experimental group significantly outperformed those in the control group in both metacognitive awareness and mathematics achievement. Usability testing indicated superior performance in attractiveness, efficiency, accuracy, stimulation, and novelty, with clarity rated as good. Interview analysis further revealed that the model increased student motivation, engagement, and vocational relevance in mathematics learning.

Conclusion. The vocational case-based mathematics learning model effectively improves metacognitive awareness and mathematics achievement while making mathematics more contextual and meaningful for vocational students. By embedding mathematics in familiar vocational contexts, the model increases motivation and helps students recognize its relevance to their future careers.

1. Introduction

Mathematics is the oldest intellectual instrument, originally used to calculate and record numbers (Buston, 2011). It involves logical thinking, rationalization, knowledge, and application (Adenegan, 2011), and is widely recognized as one of the most useful sciences for humanity (Chesky & Wolfmeyer, 2020). For thousands of years, mathematics has been part of the intellectual life of every civilized person (Courant, Robbins & Stewart, 1996). As mathematics and other scientific disciplines continue to develop, mathematics education has also evolved (Kilpatrick, 2020), emphasizing its crucial role in students' holistic development and its practical significance in everyday life (Cotič et al., 2024).

Mathematics is primarily considered a tool for solving practical problems of varying difficulty (Blum et al., 2003). Its depth is not related to mathematics itself, but to its practice (Ernes, 1991). Through consistent practice, students begin to recognize the depth and value of mathematics. Much like maturity, mathematical awareness cannot be taught directly; instead, it develops through epistemological engagement within mathematical culture (Kaenders & Kvasz, 2015). When students engage with cases or real situations, they tend to develop greater enthusiasm for learning mathematics. Home-based activities involving mathematical reasoning have been shown to strengthen mathematical skills (Elliott & Bachman, 2018; Daucourt et al., 2021), and in classroom settings, teachers can enhance mathematical awareness through technology-supported instruction (James, 2016).

Mathematics plays a crucial role in everyday life, including decision-making, financial management, problem-solving, and critical thinking (Celestine, 2024). Mathematical proficiency is an important predictor of success in modern society (Mata et al., 2012). In vocational schools, mathematics is included in the curriculum because many professional tasks require quantitative reasoning (Thiering et al., 1992). Awareness of the importance of mathematics skills related to the skills required by future careers and participation in the labor market (Farkačová, Králová & Zelendová, 2024).

In vocational education, mathematics is a key subject that prepares students for specific occupational pathways (Santos et al., 2021). It is a compulsory subject due to its significant contribution to various aspects of life and work (Adelabu, 2024). Yea & Kaci (2003) further emphasized that proficiency in mathematics greatly influences students' opportunities to pursue Science, Technology, Engineering, and Mathematics (STEM) careers and is an important determinant of future earnings.

Despite its importance, mathematics learning continues to face considerable challenges. Many students perceive mathematics as an intimidating subject. The statement "I hate math" has long expressed their anxiety and discomfort (Burn, 1975). In vocational schools, students often show low interest in mathematics, leading to persistent learning difficulties (Dalby & Noyes, 2016; Rusmar & Mustakim, 2017) and poor learning outcomes (Sumandya & Widana, 2022). Mathematics is frequently viewed as abstract and disconnected from vocational practice (Boistrup & Hällback, 2021). Students tend to prioritize vocational content and overlook how essential mathematics is to mastering vocational competencies.

These conditions indicate a fundamental problem in vocational mathematics learning: students fail to perceive the relevance of mathematics to their vocational field. This lack of perceived relevance contributes to low engagement, weak metacognitive regulation, and limited mathematics achievement. Without instructional approaches that explicitly connect mathematical concepts to vocational contexts, students struggle to develop the awareness, motivation, and self-regulation needed for meaningful mathematics learning.

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The information above indicates that there is still much room for improvement in mathematics learning. Teachers and parents recognize that mathematics remains a difficult subject for most students. Both students and teachers experience anxiety in mathematics learning (Kellar, 2003): students become anxious because they face persistent difficulties in understanding mathematical concepts, while teachers experience anxiety due to challenges in effectively facilitating learning. Addressing the gap between mathematics content and vocational relevance is therefore essential for creating meaningful learning experiences (Dalby & Noyes, 2015).

Although various approaches have been introduced to improve mathematics learning in vocational schools, previous studies have rarely integrated vocational cases with mathematical concepts in a systematic instructional model. Existing research on case-based learning also tends to focus on conceptual understanding or problem-solving, but not on strengthening metacognitive abilities, even though metacognition is a strong predictor of mathematics achievement. This gap indicates the need for instructional innovations that simultaneously contextualize mathematics within vocational practice and foster students' metacognitive development.

Efforts to improve mathematics learning outcomes are still needed, including curriculum improvements, learning optimization, teacher quality enhancement, facility enhancements, and improvements to the learning environment. Therefore, an instructional model that explicitly links mathematical concepts to vocational cases while promoting metacognitive regulation is urgently required to bridge the existing gap and support more meaningful mathematics learning for vocational students.

Numerous attempts have been made to alleviate students' difficulties in learning mathematics, such as offering remedial programs (Mattuvarkuzhali, 2012; Byiringiro, 2024; Low et al., 2024), implementing problem-based learning (Jatisunda et al., 2024), utilizing real objects (Da, 2022), or developing learning modules (Kertiyani & Oktavihari, 2025). However, these efforts have not fully addressed the core challenge, as many students still fail to perceive the benefits of mathematics in their daily lives (Adelabu, 2024).

A crucial issue in mathematics learning is how students can learn mathematics effectively and efficiently. Student success is strongly influenced by metacognitive abilities (Doudin & Meilan, 2012). Metacognition positively affects mathematical problem-solving (Tachie, 2019; Güner & Erbay, 2021; Güner & Erbay, 2021). and is recognized by the OECD as a fundamental skill assessed in PISA (OECD, 2018). Metacognition refers to individuals' knowledge about their cognitive processes and their ability to control, monitor, and regulate these processes (Anderson & Krathwohl, 2001). It involves the capacity to articulate existing knowledge and apply it to new learning situations.

Metacognition, first introduced by John Flavell in 1976 as an individual's awareness of their own cognitive abilities (Cantoia et al., 2012), is often defined simply as "thinking about thinking" (Jalil & Siq, 2009). Dawson (2008) further conceptualized metacognition as a set of interconnected competencies, including active learning, critical thinking, problem-solving, decision-making, and strategic planning. Individuals with strong metacognitive skills can consciously apply these abilities to new knowledge and novel situations.

Metacognitive skills allow students to monitor and regulate the quality of their learning to achieve their academic goals (Riwayatiningsih et al., 2022). Numerous studies have demonstrated that metacognitive abilities significantly improve students' learning outcomes (Teng et al., 2021). A review of 179 papers by Shen & Liu (2011) found that metacognition was the strongest predictor among 200 variables influencing learning outcomes. By helping students understand and regulate their own learning processes, metacognitive skills support the development of effective learners and contribute to higher academic achievement (Stanton et al., 2021).

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Efklides (2012) identified a new aspect of metacognition, namely socially shared metacognition, which plays a crucial role in collaborative learning. Enhanced metacognitive ability increases the frequency and quality of interactions, ultimately strengthening students' knowledge construction (Sumadyo et al., 2021). Students with strong metacognitive skills also tend to perform better on academic tasks (Faradiba et al., 2022). Moreover, metacognitive skills enable learners to think proactively, take deliberate actions to understand concepts, and engage in self-reflection to monitor their progress (Ergen & Kanadli, 2017).

Metacognition encompasses several forms of knowledge: declarative knowledge, referring to awareness of one's cognitive abilities; procedural knowledge, or general strategies used across tasks; and conditional knowledge, which concerns understanding when and why certain strategies should be applied (Erskine, 2009). Similarly, Zhang and Zhang (2018) conceptualize metacognition as consisting of metacognitive knowledge, metacognitive experiences, and metacognitive strategies. Collectively, these perspectives indicate that metacognitive ability comprises both knowledge and regulation.

Metacognition involves the capacity to clarify prior knowledge and use it to plan learning strategies, select essential steps in problem-solving, reflect on learning outcomes, and modify approaches when needed (Dawson, 2008). Through metacognition, students can choose appropriate cognitive tools to complete learning tasks effectively. This underscores the importance of cultivating students' awareness of the value of mathematics as a foundation for enhancing their metacognitive abilities in mathematics learning.

The present study seeks to foster students' mathematical awareness by developing a vocational case-based mathematics learning model. In this model, vocational concentration content is presented as cases whose solutions require the application of relevant mathematical concepts. Integrating mathematics into vocational material has been shown to enhance the effectiveness of mathematics learning (Mišútová & Mišút, 2023).

Students' awareness of the benefits of mathematics is strengthened when mathematical concepts are meaningfully integrated into vocational curriculum materials. This approach is expected to address students' lack of interest in mathematics, which often arises because vocational mathematics is taught in isolation, separate from vocational practice. When the perceived relevance is absent, students tend to undervalue mathematics and focus solely on vocational content.

Case-based learning involves engaging students in analyzing and discussing real-world cases. Cases are typically narrative in nature and structured around meaningful issues intended to stimulate interest (Herreid, 2007). Case-based learning requires students to examine data, consider multiple perspectives, and draw conclusions. Because cases are open-ended, students must decide which analytical techniques are most appropriate. Teachers who implement case-based learning often report higher levels of student engagement, interest, and participation (Thistlethwaite et al., 2012). In contexts where curricula are dense and instructional time is limited, case-based learning becomes a practical and effective option, particularly for small-group learning (Srinivasan et al., 2007).

Case-based learning enhances relevance and helps students connect theoretical concepts to real-world practice, producing outcomes that range from improved conceptual understanding to enhanced practical skills (McLean, 2016). Students construct knowledge by organizing information, analyzing it, and applying it to new situations under the guidance of a facilitator (Das et al., 2021). When mathematical concepts are integrated into vocational cases, students are expected to develop greater awareness of the value of mathematics within their vocational field. Embedding mathematical content into vocational contexts makes learning more meaningful and authentic. Contextualized instruction allows students to recognize the potential applications of their knowledge in the real world, particularly through work-integrated or case-based learning approaches (Osika et al., 2022).

Contextual learning occurs when students process new information by relating it to their own frame of reference (Salminen, 2024). Case-based learning that integrates mathematical concepts into vocational content exemplifies this approach. By engaging with vocational cases drawn from their daily experiences, students learn mathematics in ways that feel familiar and meaningful. This integration of content and context enables learners to recognize the usefulness of what they study, strengthens the authenticity of classroom activities, and supports the construction of new knowledge from prior understanding.

Rather than separating theory from practice, contextual case-based learning encourages students to solve problems situated within real vocational scenarios while simultaneously learning the underlying mathematical concepts (Salminen, 2024). For instance, when studying electrical systems, students also explore the mathematical principles embedded in those systems. Through hands-on activities, trial-and-error, and reflection, learners develop a deeper understanding of concepts and skills. Because these learning experiences occur within social and professional contexts where the knowledge will be applied, students can identify practical connections from the outset. The cases used in instruction are intentionally open-ended, as such problems promote flexible thinking and allow students to explore multiple solution pathways (Yeo, 2017; Munroe, 2015).

Given the persistent disconnect between vocational mathematics content and students' actual vocational experiences, developing a learning model that situates mathematics within authentic vocational cases is critical. Addressing this need is significant because such a model has the potential to increase students' perceived relevance of mathematics, strengthen their metacognitive regulation, and ultimately improve their learning outcomes in both mathematics and vocational subjects. Building on this rationale, the present study aims to develop and test a vocational case-based mathematics learning model that integrates mathematical concepts into vocational cases, with the specific objective of enhancing students' metacognitive abilities and their achievement in mathematics. Accordingly, the study addresses the following research questions:

1) Does the vocational case-based mathematics learning model improve vocational students' metacognitive abilities? 2) Does the vocational case-based mathematics learning model improve vocational students' mathematics learning achievement?

To empirically examine these questions, the study formulated two hypotheses: (H_1) students who receive instruction through the vocational case-based mathematics learning model will demonstrate significantly higher metacognitive abilities than those who receive conventional instruction; and (H_2) students taught using the model will achieve significantly higher mathematics learning outcomes compared to their counterparts in the control group.

2. Literature Review

2.1. Mathematics in Vocational Education

Mathematics plays a vital role in vocational education because many occupational tasks require quantitative reasoning, measurement, and problem-solving (Thiering, Hatherly, & McLeod, 1992; Santos et al., 2021). Studies have shown that mathematics proficiency significantly influences vocational students' preparedness for the labor market and STEM-related professions (Yea & Kaci, 2023; Farkačová, Králová, & Zelendová, 2024). However, mathematics is often undervalued in vocational schools, with students perceiving it as disconnected from their vocational goals (Dalby & Noyes, 2016; Rusmar & Mustakim, 2017). As a result, students' mathematics achievement remains low, despite its relevance to their career pathways (Sumandya & Widana, 2022). Although previous studies acknowledge the essential role of mathematics in vocational preparation, they rarely examine instructional models that explicitly integrate mathematics into vocational content to strengthen perceived relevance. This indicates a gap in pedagogical approaches that connect mathematics with authentic vocational contexts.

2.2. Challenges in Vocational Mathematics Learning

Research indicates that vocational students frequently experience anxiety and negative attitudes toward mathematics (Kellar et al., 2003; Buabeng-Andoh, 2019). Traditional mathematics instruction often emphasizes abstract theories, reinforcing the belief that mathematics is irrelevant to vocational practice (Boistrup & Hällback, 2021). Several interventions, such as remedial classes (Mattuvarkuzhali, 2012; Byiringiro, 2024), problem-based learning (Jatisunda, Suryadi, & Prabawanto, 2024), and the use of real objects or modules (Da, 2022; Kertiyani & Oktavihari, 2025), have attempted to make mathematics more accessible. Nevertheless, these approaches have not fully addressed the issue of contextualizing mathematics in authentic vocational settings. While the existing interventions improve engagement and accessibility, they do not explicitly integrate mathematical concepts into vocational contexts in a systematic and sustained way. Thus, there remains a clear need for a learning model that directly links mathematics with vocational tasks so that students can understand its relevance and reduce negative perceptions toward mathematics.

2.3. Metacognition and Mathematics Learning

A growing body of research highlights the importance of metacognition in students' ability to plan, monitor, and evaluate their thinking in improving mathematics learning (Anderson & Krathwohl, 2001; Dawson, 2008). Metacognitive skills have been found to positively influence mathematical problem-solving and achievement (Tachie, 2019; Güner & Erbay, 2021). Meta-analyses indicate that metacognition is among the strongest predictors of learning outcomes across disciplines (Shen & Liu, 2011). In vocational education, strengthening students' metacognition can promote independence and the ability to transfer mathematical knowledge to real-world tasks (Riwayatiningsih et al., 2022). However, studies rarely explore pedagogical models specifically designed to enhance metacognitive skills in vocational mathematics learning. However, despite its importance, existing studies have rarely examined instructional models that intentionally cultivate metacognitive processes through contextualized vocational activities. Prior research tends to treat metacognition as an outcome variable rather than a target of pedagogical innovation, leaving a gap regarding how learning models can be purposefully structured to simultaneously support contextual learning and metacognitive regulation. This gap highlights the need for approaches that integrate mathematical thinking with vocational tasks while explicitly enhancing students' metacognitive abilities.

2.4. Case-Based Learning as a Pedagogical Strategy

Case-based learning (CBL) has been widely applied in medical, health, and STEM education to foster active engagement, critical thinking, and contextual understanding (Herreid, 2007; Thistlethwaite et al., 2012; McLean, 2016; Tsekhmister, 2023). CBL situates learning in real-world scenarios, enabling students to connect theory with practice (Das et al., 2021; Boonheang & Cojorn, 2025). Recent studies highlight its effectiveness in stimulating motivation and higher-order thinking (Sistermans, 2020; Embodo, 2024). However, in vocational education, case-based learning has primarily been used for technical or professional training, with limited integration of mathematical concepts. This presents an opportunity to explore how CBL can serve as a bridge between mathematics and vocational subjects. Despite these advantages, research on CBL in vocational education has predominantly focused on technical or domain-specific training, such as engineering procedures or workplace simulations, with minimal emphasis on embedding mathematical concepts within vocational contexts. Existing applications of CBL rarely position mathematics as an integral part of the cases, resulting in limited insight into how CBL can be leveraged to strengthen mathematical understanding in authentic vocational contexts.

Furthermore, no prior studies have examined the potential of CBL to enhance metacognition in vocational mathematics learning, even though both contextualization and metacognitive regulation are essential for supporting transfer of learning. This presents a meaningful gap and opportunity to investigate how a vocationally contextualized case-based learning model can serve as a bridge between mathematics, vocational practice, and metacognitive development.

3. Methodology

The vocational case-based mathematics learning model was developed by adopting five key components of instructional models proposed by Joyce and Weil (1986): syntax, social system, principles of reaction, support system, instructional effects, and nurturant effects. Syntax refers to the sequence of learning steps; the social system encompasses classroom roles and norms; the principles of reaction describe how teachers respond to student behavior; the support system includes materials and tools needed for implementation; and instructional and nurturant effects represent the expected primary and secondary learning outcomes. Given its dual aim of developing and empirically testing an instructional model, this study used a mixed-methods Research and Development (R&D) approach. The development stage emphasized qualitative procedures, expert review, iterative refinement, and model validation, while the testing stage employed quantitative quasi-experimental procedures. Positioning the study as mixed-methods clarifies that qualitative and quantitative evidence were systematically integrated throughout the research process.

The model development followed Borg and Gall's (2003) ten-step R&D procedure, including information gathering, planning, prototype development, prototype evaluation, model revision, and dissemination. Initial information collection was conducted through literature studies and field surveys. A prototype was then created and evaluated qualitatively by six experts—two mathematics education specialists, two instructional design experts, and two language experts. Feedback from these experts was used to revise and refine the model through multiple cycles.

Subsequently, the model's validity was examined through a Focus Group Discussion (FGD) involving seven participants: two vocational mathematics teachers, one vice principal for curriculum, two vocational education experts, and two mathematics education lecturers. After validation, the model was tested for effectiveness using a non-equivalent pretest–posttest control group design (Campbell & Stanley, 1963; Denny et al., 2022). Purposive sampling was used to select two parallel classes with comparable academic characteristics, following recommendations from school administrators to ensure group equivalence. Assignment to experimental and control groups followed the existing classroom structure, consistent with the principles of non-equivalent group design. The class assignment followed the school's existing structure—one class (n = 30) served as the experimental group receiving the vocational case-based mathematics learning model, and the other class (n = 30) served as the control group receiving conventional case-based instruction. Experimental implementation occurred in two stages: an initial trial at SMK Negeri 1 Singaraja and a final trial involving 60 students at SMK Negeri 3 Singaraja.

Data on metacognitive awareness were collected using an instrument based on Schraw and Denison's (1994) indicators, consisting of two components: cognitive knowledge (declarative, procedural, conditional) and cognitive regulation (planning, organizing, processing, monitoring, evaluating). Students were asked to complete the mathematics test and answer several questions related to metacognitive abilities (Fortunato et al., 2001; Nool, 2012; Kwang, 2000). The instrument included 15 non-routine mathematical tasks scored on a scale of 1–8. Administration took place in a paper-based format under standardized testing conditions, with all students completing the assessment in a single 90-minute session to ensure consistency.

Mathematics achievement data were collected using a performance test instrument (Salsabila et al., 2020; Chytry & Kubiatko, 2021; Age, 2025). The instrument consisted of 10 items, each with a score range of 1-10. Prior to use, the metacognitive awareness and mathematics achievement instruments were tested for validity using the Lawshe technique (Lawshe, 1975) and for reliability using Cronbach's alpha (Bonett & Wright, 2014). The Cronbach's Alpha coefficients for the metacognitive awareness instrument and mathematics achievement were 0.78 and 0.82, respectively. Both instruments were suitable for use because they exceeded the reliability limit of 0.70 (Nunnally, 1978). In addition to collecting data on metacognitive awareness and mathematics achievement, data were collected at the end of the experiment to test the model's usefulness using the User Experience Questionnaire (UEQ). The UEQ consists of 26 semantic difference items with a score range of 1-7, measuring six aspects: attractiveness, efficiency, accuracy, stimulation, novelty, and clarity (Schrepp, 2023). The usability test was administered only to teachers and students in the experimental group, as only they had experience using the developed learning model. All UEQ items were administered electronically via the school's LMS, and respondents completed the instrument individually, without time limits, to avoid pressure or bias.

UEQ data were analyzed descriptively to obtain an overview of the model's usability, following Schrepp's (2023) guidelines. Data analysis was then conducted to test the hypotheses by comparing metacognitive awareness and learning outcomes between the experimental and control groups. One-way multivariate analysis of Variance was used for the analysis. The quantitative data analysis followed standard MANOVA procedures, beginning with assumption testing (multivariate normality, homogeneity of variance–covariance matrices, and multicollinearity checks), followed by significance testing using Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root. Prior to data analysis, prerequisite tests were conducted, including a normality test, homogeneity-of-variance and covariance tests, and correlations among dependent variables to ensure there was no multicollinearity. All analyses were performed using SPSS version 26. In addition to the quantitative analysis, qualitative interview data were analyzed using thematic analysis following Braun and Clarke's (2006) framework. The analysis involved generating initial codes, organizing them into potential themes, reviewing and refining theme structures, and ensuring credibility through repeated cross-checking of coded segments.

4. Results

4.1. Validation of the Learning Model

The validity of the vocational case-based mathematics learning model was confirmed through expert judgment and focus group discussions (FGDs). Six experts, specialists in mathematics education, instructional design, and language, reviewed the vocational case-based mathematics learning model and evaluated its suitability for implementation. Their assessments examined the model based on the five key components (Joyce et al., 1986): syntax, social system, principles of reaction, support system, and instructional/nurturant effects. Overall, the expert panel concluded that the model demonstrated clarity, feasibility, and strong alignment with vocational mathematics learning needs.

FGDs involving vocational mathematics teachers and members of the development team provided additional validation. Participants emphasized that the model supported metacognitive development, enhanced mathematics achievement, fostered collaboration and mutual respect, and promoted other complementary learning outcomes. The qualitative inputs were analyzed using thematic analysis, enabling the identification of recurring patterns in usability and instructional impact. Table 1 summarizes the validation results.

Table 1. Expert Validation of the Vocational Case-Based Mathematics Learning Model

Component	Validation Focus	Expert Judgment*
Syntax	The steps for establishing, analyzing, and concluding cases are clear and systematic.	Appropriate
Social System	Student-centered interactions, collaborative group discussions	Appropriate
Principles of Reaction	Teacher scaffolding and feedback responses support learning	Appropriate
Support System	E-learning portal and case materials are relevant and accessible	Appropriate
Instructional Effects	Improvement of metacognition and mathematics achievement	Appropriate
Nurturant Effects	Development of collaboration, mutual respect, and learning skills	Appropriate

*Judgments are summarized from expert evaluations (mathematics education, language, instructional design).

4.2. Effectiveness on Metacognitive Awareness and Mathematics Achievement

Table 2 shows the mean scores of metacognitive awareness and mathematics achievement for both the experimental and control groups. The data reveal that students taught using the vocational case-based mathematics learning model outperformed those taught with the conventional case-based approach. Specifically, the experimental group achieved higher mean scores on metacognitive awareness ($M = 93.73$, $SD = 5.23$) than the control group ($M = 88.53$, $SD = 4.36$). Likewise, the experimental group obtained higher mathematics achievement scores ($M = 86.07$, $SD = 4.77$) than the control group ($M = 80.80$, $SD = 7.02$). These findings indicate that embedding mathematical concepts into vocational contexts enhances students' ability to regulate their learning and improves their mastery of mathematical content.

Table 2. Mean Score of Metacognitive Ability and Mathematics Achievement

	Group	Mean	Std. Deviation
Metacognitive	Eksperiment	93.73	5.230
	Control	88.53	4.357
	Total	91.13	5.419
Achievement	Eksperiment	86.07	4.773
	Control	80.80	7.022
	Total	83.43	6.479

Before testing the hypothesis, assumption checks were performed to ensure the suitability of MANOVA. The Q–Q plot of Mahalanobis distances and chi-square distribution confirmed multivariate normality, and the correlation between the dependent variables ($r = .267$) indicated no multicollinearity, as it remained below the .80 threshold. Additionally, Box's M test showed that the variance–covariance matrices were homogeneous (Box's M = 4.375, $p = .258 > .05$), confirming that the dataset met the required statistical assumptions.

Table 3 presents the results of the One-Way MANOVA. The analysis revealed a significant multivariate difference between the experimental and control groups on the combined dependent variables, Wilks' $\Lambda = .676$, $F(2, 57) = 6.48$, $p = .005$, partial $\eta^2 = .32$. This medium-to-large effect size indicates that the vocational case-based mathematics learning model produced meaningful improvements in both metacognitive awareness and mathematics achievement, outperforming the conventional case-based approach.

Table 3. One-Way MANOVA Results for Metacognitive Awareness and Mathematics Achievement

Effect		Value	F	Sig.
Group	Pillais's Trace	.324	6.481	0.005
	Wilks' Lambda	.676	6.481	0.005
	Hotelling's Trace	.480	6.481	0.005
	Roy's Largest Root	.480	6.481	0.005

4.3. Usability and User Experience of the Model

The usability of the vocational case-based mathematics learning model was evaluated using the User Experience Questionnaire (UEQ) and supported by interview data from teachers and students in the experimental group. The UEQ assessed six dimensions of usability: attractiveness, efficiency, accuracy, stimulation, novelty, and clarity. As shown in Table 4, the model achieved superior ratings across five dimensions, with clarity rated at a good level.

Table 4. Usability Test Results Based on the User Experience Questionnaire (UEQ)

Aspect	M	SD	Interpretation
Attractiveness	5.9	0.8	Superior
Efficiency	5.8	0.9	Superior
Accuracy	5.7	0.7	Superior
Stimulation	5.6	0.8	Superior
Novelty	5.5	0.9	Superior
Clarity	4.9	1.0	Good

Note: UEQ uses a 1–7 scale; scores above 5.5 are considered "Superior," 4.5–5.4 "Good." (Adapted from Schrepp, 2023).

The results indicate that the model was perceived as engaging and effective, enabling both students and teachers to work efficiently and accurately while keeping learning stimulating and novel. The relatively lower clarity score suggests the need for minor refinement of instructions and supporting materials to further strengthen user comprehension.

To complement these quantitative findings, interviews with teachers and students were analyzed thematically. A total of 10 participants (3 teachers and seven students) participated in the interviews, and the transcripts were coded using a thematic analysis approach to identify key patterns of user experiences. These recurring patterns were grouped into themes and sub-themes, with relative frequencies and illustrative responses presented in Table 5.

Table 5. Themes and Sub-Themes from Teacher and Student Interviews

Stakeholder	Main Theme	Sub-Themes / Aspects Identified	Frequency*	Example Responses**
Teachers	Classroom management	- Time efficiency - Ease of implementation	High	"The model made teaching easier and saved class time."
	Student engagement	- Active participation - More focused group discussions	Medium	"Students were more focused and engaged in discussions than in regular lessons."
	Instructional support	- Vocational context aids explanation - Materials are useful	Medium	"Cases from their field helped me explain abstract math concepts more clearly."
Students	Motivation & interest	- Increased enjoyment of math - Learning feels less abstract	High	"We were more interested because the cases are from our own field."
	Relevance to practice	- Connection to vocational tasks - Value for future careers	High	"Mathematics feels useful for our future work."
	Peer collaboration	- Sharing ideas - Peer tutoring - Brainstorming impact	Medium	"We often helped each other solve the cases — it made math easier to understand."

*Frequency is relative (High = mentioned by most participants, Medium = mentioned by several participants).

**Responses are paraphrased from interview data.

The qualitative findings reinforce the UEQ results, particularly in the dimensions of attractiveness, stimulation, and efficiency. Teachers emphasized time efficiency and classroom management support, while students highlighted motivation, enjoyment, and the vocational relevance of mathematics learning. The interviews also revealed that peer collaboration and familiarity with vocational contexts played a crucial role in facilitating deeper engagement, supporting users' positive experience with the model.

5. Discussion

The results of this study confirm that the vocational case-based mathematics learning model is effective in improving students' metacognitive awareness and mathematics achievement. These findings directly address the study's objective to integrate mathematical concepts into vocational cases to enhance both cognitive regulation and mathematics mastery. In line with this purpose, the discussion first summarizes the key outcomes and then interprets them through relevant theoretical and empirical lenses. These findings align with the broader literature indicating that case-based learning is highly flexible (McLean, 2016) and can be adapted to integrate real-world contexts into the classroom (Tsekhmister, 2023). By embedding mathematics learning within vocational cases, the model creates a more contextualized learning experience that encourages students to solve problems relevant to their fields of study (Salminen, 2024). This relevance enhances active engagement, fosters independence, and promotes collaboration in ways consistent with previous reports on the benefits of case-based learning (Boonheang & Cojorn, 2025; Sistermans, 2020).

The vocational orientation of the cases further supports meaningful learning by connecting mathematical concepts to students' daily activities and future careers. This is consistent with Perez et al. (2023), who emphasized the importance of designing case materials that support individual and collective learning in contextual environments. Such environments provide students with opportunities to think consciously and purposefully, which is central to developing metacognitive skills (Wahba et al., 2022; Samsonovich et al., 2008). In this study, students reported that the vocational cases increased their motivation, as they clearly perceived the usefulness of mathematics for both their current learning and their intended professions. These findings fill an overlooked gap in earlier research, which has largely applied case-based learning in technical or professional subjects but has rarely integrated mathematical reasoning into vocational cases to explicitly promote metacognition.

Qualitative feedback from teachers and students also reinforces the model's effectiveness. Teachers noted improvements in classroom efficiency and student engagement, while students emphasized that their familiarity with vocational contexts made the learning process more meaningful. These findings echo the work of Ishak et al. (2025), who found that cultural and contextual familiarity can act as a mediator in enhancing the effectiveness of metacognitive strategies. Similarly, the collaborative aspects of the model, particularly group discussions, brainstorming, and peer tutoring, reflect the mechanisms by which case-based approaches stimulate higher-order thinking and peer learning (Embodo, 2024). Together, these patterns demonstrate that the model not only supports individual metacognitive regulation but also cultivates socially shared metacognition, which is essential in collaborative learning environments.

Moreover, the model aligns with broader educational goals of making mathematics a tool for interpreting and interacting with everyday life. As Ding (2022) observed, mathematics education should enable students to discover patterns and rules that shape their experiences in the world. When students understand the value of mathematics in daily and professional contexts, they are more motivated to practice it (Buabeng-Andoh, 2019). They are better prepared to succeed in further learning and in careers requiring mathematical competence (Farkačová et al., 2024). The results, therefore, highlight how contextualizing mathematics within vocational cases can strengthen both cognitive and motivational dimensions of learning, an outcome rarely documented in prior vocational education research.

Taken together, these findings highlight both the theoretical and practical contributions of vocational case-based mathematics learning. Theoretically, the study extends case-based learning by embedding it in vocational contexts, thereby reinforcing its role in promoting metacognition and achievement. Practically, the model offers teachers a systematic and time-efficient approach to making mathematics more engaging and relevant for students in vocational education. This contribution is particularly significant because earlier interventions (e.g., remedial classes, real objects, and problem-based learning) have not fully succeeded in contextualizing mathematics in authentic vocational settings.

For practitioners, the model can serve as a framework for designing mathematics instruction that aligns more closely with vocational tasks. For policymakers, the results highlight the need to support curriculum designs that integrate mathematics and vocational content. Future studies may investigate long-term impacts, applicability across different vocational fields, and how digital tools might further enhance case-based mathematics learning.

6. Conclusion

The vocational case-based learning model integrates mathematical concepts into vocational concentration materials. The cases used in learning are contextualized by selecting vocational cases that contain the mathematical concepts to be learned. This model creates an interactive learning experience and creates a lasting impression because students experience the benefits of learning mathematics. Specifically, the characteristics of the vocational case-based mathematics learning model are: 1) learning focuses on developing students' awareness of the importance of mathematics in vocational learning and their future careers; 2) the learning process is interactive because the material is contextualized, so students already feel familiar with it; 3) abstract mathematical material is brought to real-world applications, so students feel like they are learning vocational material, even though they are also learning mathematics; 4) it emphasizes observation and exploration supported by cases familiar to students; and 5) it supports collaborative learning.

The vocational case-based mathematics learning model fulfills the five main elements of a learning model: syntax, principles of reaction, social systems, support systems, instructional effects, and nurturant effects. Expert assessment and experiments found that the model meets the requirements of validity, usability, and effectiveness in increasing metacognitive ability and mathematics learning achievement. Students' awareness of the benefits of mathematics is built through connections between mathematics and vocational programs, which further increase their interest and motivation in learning mathematics. The model also provides opportunities for students to understand their future mathematics learning needs and consider careers that require mathematics skills.

Theoretically, this study contributes to the literature by extending case-based learning into vocational contexts, demonstrating that contextualizing mathematical concepts within discipline-specific cases can significantly enhance metacognitive processes and learning outcomes. In practice, the model provides teachers with a structured, time-efficient approach to designing mathematics instruction that is relevant, engaging, and aligned with the needs of vocational education.

Based on these findings, teachers are encouraged to integrate vocational cases more systematically into mathematics instruction. At the same time, policymakers may consider supporting curriculum designs that strengthen connections between mathematics and vocational fields. Future research may explore the application of this model across other vocational specializations, investigate its integration with digital learning environments, or examine its long-term impact on students' career readiness and mathematical competence.

7. Suggestion

The contribution of this research is in the effort to find alternative mathematics learning models for vocational schools. Further research is needed to adapt learning models to individual student needs to ensure lifelong mathematics learning.

Declarations

Author Contributions. Ni Made Sri Mertasari: Conceptualization, writing, original manuscript preparation, literature review, methodology, and supervision. I made Candida: Data collection, data analysis, validation, and critical review. Abas Oya: Editing, manuscript refinement, and preparation of the final draft for submission.

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Data Availability Statement. The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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